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## REVIEW ARTICLE

# Delayed polishing technique on glass–ionomer restorations

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## KEYWORDS

Interfacial gap-formation;  
Delayed polishing;  
Class I restoration;  
Class V restoration;  
1-day storage

**Summary** This *in vitro* study evaluated the effect of polishing after 1-day storage in water on the gap-formation around a Class V and Class I restorations, using a resin-modified glass–ionomer and a conventional glass–ionomer materials. The study also examined the gap-formation in another two different cervical restorations, a cervical cavity: incisally bordered by enamel and cervically by dentin and a root surface cavity of these restorative materials, which may be effects of this polishing procedure. This study evaluated the effects of delayed *versus* immediate polishing to permit maturation on: (1) interfacial gap-formation around resin-modified (RMGIC) and conventional (CGIC) in three types of cervical restorations, (2) interfacial gap-formation around highly viscous conventional glass–ionomer cement (HCGIC) in Class I restorations. After polishing procedure, either: (i) immediately (3 or 6 min) after setting or (ii) after 24 h storage, the maximum the restored teeth were sectioned in a mesio-distal direction through the center of the restorations. The presence or absence of interfacial-gaps was measured at 14 points (each 0.5-mm apart) along the cavity restoration interface. For various restorative cases, significant differences ( $p < 0.05$ ) in gap-width or gap-incidence, were observed between polishing (i) immediately and (ii) after 1-day storage.

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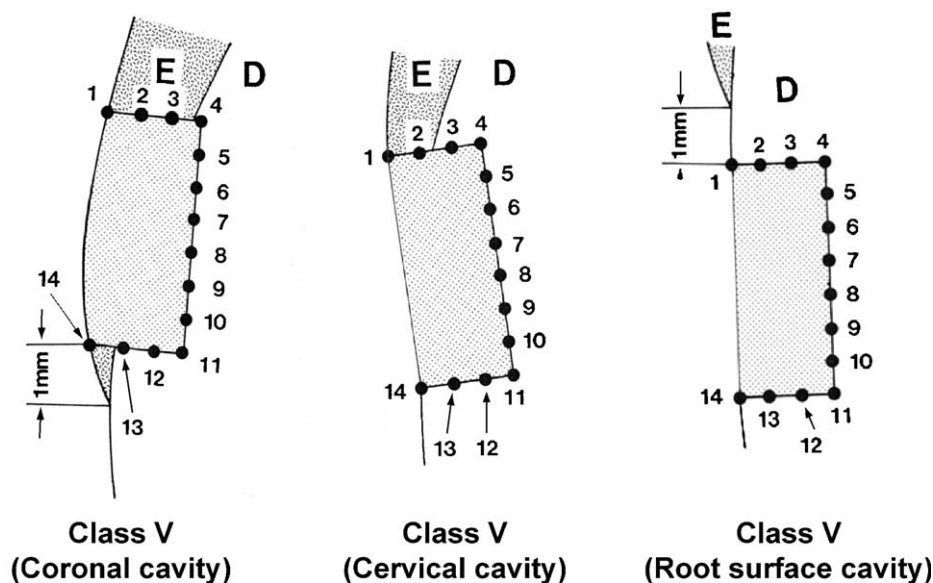
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## 1. Objectives

Cervical restorations may be created with both conventional glass–ionomer cement (CGIC), and resin-modified glass–ionomer cement (RMGIC) [1–8]. CGICs have several beneficial properties, such as physicochemical bonding to the tooth substrate, fluoride release and uptake and tooth color. However, they also demonstrate brittle fracture, erosion and wear in the oral environment [9]. To reduce these deficiencies, RMGICs were developed. These cements have a dual setting reaction consisting of an acid–base reaction and a photochemical polymerization process. The final set materials have a complex structure in which glass particles are sheathed in a matrix consisting of two networks—one

derived from the glass ionomer, the other from the resin [10,11]. In these dual setting systems, the resin reinforcement provides higher mechanical strength and higher bond strength to tooth surfaces, compared with CGICs [12–15]. Thus RMGIC materials may exhibit improved marginal seal and reduced interfacial gap-formation by hygroscopic expansion [13,14] and improved bonding ability after 24 h water storage [13–17].

An important clinical variable was to be assessed in this connection: namely, the effect on these properties of an immediate *versus* a 24 h-delayed polishing procedure. Hence, a major hypothesis to be tested was that *premature polishing would significantly reduce gap-formation integrity, relative to delayed polishing*.



**Figure 1** Three kinds of cervical restoration and each measured point in the cervical restoration. E: enamel substrate, D: dentin substrate, G: glass ionomer restorative material.

## 2. Effects of delayed polishing on gap-formation of cervical restorations

### 2.1. Procedure

#### 2.1.1. The cavity region: coronal cavity restoration

A cavity preparation was placed parallel to the cement–enamel junction (CEJ) with the preparation extended 1.0 mm above the CEJ (Fig. 1, completely bordered by enamel: coronal cavity) [18].

#### 2.1.2. Inspection procedure #1

Immediately after light curing or setting, each tooth was sectioned in a buccolingual direction through the center of the restoration with a low-speed diamond saw (Isomet, Buehler Ltd., Lake Bluff, IL). Thus, the presence or absence of marginal gap was measured at 14 points (each 0.5 mm apart) along the cavity restoration interface ( $n = 10$ , total points measured = 140). This was done with a traveling microscope ( $\times 1000$ , Measurescope, MM-11, Nikon, Tokyo, Japan) positioned parallel with the cavity wall and bottom on each half of the sample (Fig. 1). The number of gaps in each sample was totaled and expressed as the sum of each sample.

#### 2.1.3. Inspection procedure #2

Immediately after light curing or setting, the surface of restorations was polished with abrasive points (Silicone Mide, Shofu, Kyoto, Japan) and through rinsing with distilled water. Measuring a specimen involved the same procedure as described above.

#### 2.1.4. Inspection procedure #3

After polishing and inspecting as described above (Inspection procedure 2), the specimen was stored in distilled water at 37 °C for 1 day. Then, the presence of gaps was re-inspected as described above.

#### 2.1.5. Inspection procedure #4

The specimen was stored in distilled water at 37 °C for 1 day after light curing or setting. Next the surface of the restorations was polished as described above. Then, the presence of gaps was inspected as described above.

#### 2.1.6. The cavity region: cervical and root surface restorations

**2.1.6.1. Cervical cavity.** A cavity preparation was placed parallel to the cement–enamel junction with the center at the cement–enamel junction (Fig. 1, incisally bordered by enamel, cervically by cement or dentin, cervical cavity).

**2.1.6.2. Root surface cavity.** A cavity preparation was placed parallel to the cement–enamel junction with the preparation extending 1.0 mm below the cemento–enamel junction (Fig. 1, completely bordered by cement or dentin, Root surface cavity).

**2.1.6.3. Inspection procedure #4.** The restorative, polishing and inspection procedures were performed as described for the Inspection procedure #4.

### 2.2. Results

Table 1 summarizes data for gap-formation of *Fuji II LC* observed in the cervical restorations with various cavity regions and inspection procedures. With the two inspection procedures, cutting and immediate inspection after the setting (#1 and #2), 86 and 101 gaps around the restorative cavities, respectively, were observed. When the same specimens as described above (#2) were stored in distilled water for 1-day, then re-inspected (#3), 74 gaps around the restorative cavities were observed. No significant differences among the three conditions were observed. The severest points, 1 and 14, showed the most gaps in the three conditions. The cervical corner area, 9–11, also showed many gaps. The axial regions showed half the number of gaps in the same conditions. However, when the specimen was cut and inspected after storing in water for 1-day (#4), 17 gaps around the coronal restorative cavities were observed. Significant differences were observed among the three conditions (#1, #2, and #3) and the three #4 conditions. No significant differences among the sum of gaps of three different cavity region restorations (#4) were observed. However, when the cavity region was coronal, the polished point, 14 (enamel substrate), showed half the number of gaps in the restorative cavities. The cervical corner, 11, also showed many gaps. When the cavity

**Table 1** Effect of cavity region and inspection procedure on gap-formation around restoration (*Fuji II LC*).

Cavity region	Inspection procedure	Number of specimens showing gaps														Sum
		Coronal					Bottom						Cervical			
		①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩	⑪	⑫	⑬	⑭	
Coronal	#1	9	7	7	7	5	4	6	5	5	5	8	6	3	9	86 (A)
Coronal	#2	10	7	6	6	7	7	6	8	9	10	10	0	5	10	101 (A)
Coronal	#3	10	1	1	6	5	6	5	4	8	8	8	0	2	10	74 (A)
Coronal	#4	1	0	0	1	1	2	0	0	2	1	4	0	0	5	17 (B)
Cervical	#4	2	0	0	1	2	3	0	0	2	0	4	0	0	2	16 (B)
Root surface	#4	0	0	0	3	3	3	3	2	2	2	0	0	0	0	18 (B)

#1: light-activation (20 s) → cut → inspection (not polished). #2: light-activation (20 s) → polish → cut → inspection. #3: #2 → storage in water for 1 day → re-inspection. #4: light-activation (20 s) → storage in water for 1 day → polish → cut → inspection.  $N = 10$  (total measuring points, ①–⑭ = 140). Values with the same letters were not significantly different by Duncan's New Multiple-Range Test ( $p > 0.05$ , non-parametric [19]).

**Table 2** Effect of cavity region and inspection procedure on gap-formation around restoration (*Fuji II*).

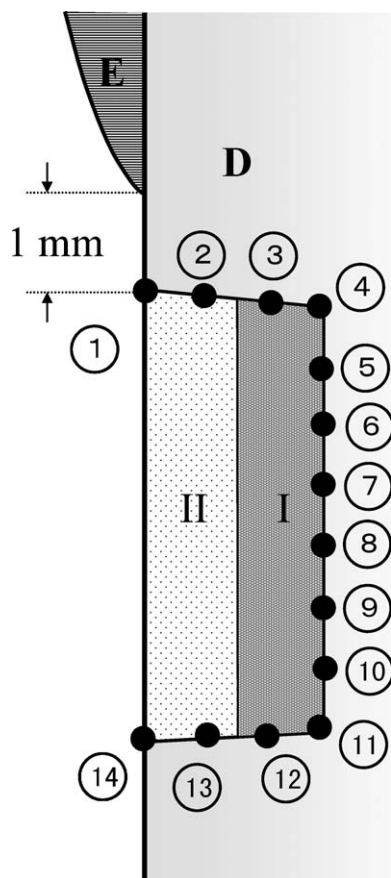
Cavity region	Inspection procedure	Number of specimens showing gaps														Sum
		Coronal				Bottom						Cervical				
		①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩	⑪	⑫	⑬	⑭	
Coronal	#1	9	5	4	4	9	8	7	8	9	9	9	5	8	10	104 (AB)
Coronal	#2	10	5	7	6	8	8	9	8	10	9	10	8	9	10	117 (A)
Coronal	#3	8	2	3	7	6	5	6	5	7	8	10	6	6	8	87 (B)
Coronal	#4	0	0	0	1	1	0	0	0	0	1	3	0	0	1	7 (C)
Cervical	#4	2	1	0	1	0	0	0	0	0	0	1	0	0	2	7 (C)
Root surface	#4	3	0	1	1	0	0	0	0	0	0	1	1	1	1	9 (C)

#1: light-activation (20 s) → cut → inspection (not polished). #2: light-activation (20 s) → polish → cut → inspection. #3: #2 → storage in water for 1 day → re-inspection. #4: light-activation (20 s) → storage in water for 1 day → polish → cut → inspection.  $N = 10$  (total measuring points, ①–⑭ = 140). Values with the same letters were not significantly different by Duncan's New Multiple-Range Test ( $p > 0.05$ , non-parametric [19]).

region was the root surface, there were 2–3 gaps in all the inspected points in the axial region 5–10.

Table 2 summarizes the data for the gap-formation of *Fuji II* observed in cervical restorations with various cavity regions and inspection procedures. With both procedures-cutting and immediate inspection after the setting (#1 and #2) 104 and 117 gaps around the restorative cavities, respectively, were

observed. When the same specimens as described above (#2) were stored in distilled water for 1-day, then re-inspected (#3), 87 gaps around the restorative cavities were observed. The #3 condition was a significantly improvement in gap-formation compared with that of #2. The severest points, 1 and 14, showed the most gaps in the three conditions. The cervical corner area, 9–11, also showed more gaps. The axial regions showed more gaps in the same conditions. However, when the specimen was cut and inspected after storing in water for 1-day (#4), only seven gaps were observed around the restorative cavities. Significant differences were observed among the three conditions (#1, #2 and #3) and the three #4 conditions. No significant differences were observed among the sum of gaps of three different cavity region restorations (#4). The polished points, 1 and 14, showed few gaps in the three restorative cavities. The presence of gaps was almost zero at all inspected points in the axial region 5–11.



**Figure 2** Root surface restoration and each measurement location for gap-formation. E: enamel substrate, D: dentin substrate. I, first layer, II, second layer.

### 3. Effects of reduced P/L ratio of the first increment and delayed polishing of root-surface gap-formation with resin-modified glass–ionomer restorations

#### 3.1. Procedure

The preparation was placed parallel to the cemento-enamel junction, extending 1.0 mm below the cemento-enamel junction (Fig. 2), and so was completely bordered by cementum or dentin. Cavo-surface walls were finished to a butt joint. One cavity was prepared in each tooth [20].

##### 3.1.1. Incremental procedure

Restorative material was applied to designated cavities with an incremental technique, as illustrated in Fig. 2. Normalized P/Ls of the first increment of *Fuji II LC* were 0.22, 0.33, 0.47, 0.60, 0.73, 0.87 and 1.0, respectively and the P/L of the second increment was constant (3.0). Approximately half the cavity was filled with the first increment. As a control, the bulk method was applied.

**Table 3** Effect of normalized powder/liquid ratio of first layer (incremental method) on interfacial gap-formation around *Fuji II LC* restorations, polished immediately after light-activation.

Normalized P/L ratios	Number of specimens showing gaps														Sum		
	Coronal				Axial						Cervical				Coronal + cervical	Axial	Total for all
	1	2	3	4	5	6	7	6	9	10	11	12	13	14			
Incremental method: first layer (P/L)/second layer (P/L) <sup>a</sup>																	
0.20	7	0	0	2	5	4	3	3	3	5	4	0	0	7	20 (NS) <sup>a#</sup>	23 (NS) b	43 (NS) c
0.33	7	0	0	3	1	3	2	2	1	2	2	0	0	7	19 (NS) a	11 (S) b	30 (S) c
0.47	7	0	0	2	1	3	2	3	0	1	3	0	0	6	18 (NS) a	10 (S) b	28 (S) c
0.60	6	0	1	2	2	3	2	1	1	1	2	0	0	6	17 (NS) a	10 (S) b	27 (S) c
0.73	6	0	1	1	2	2	4	4	3	4	6	1	0	6	21 (NS) a	19 (NS) b	40 (NS) c
0.87	7	1	0	2	4	3	4	6	4	2	3	1	1	7	22 (NS) a	23 (NS) b	45 (NS) c
1.0	7	1	3	4	3	5	2	3	3	1	5	2	0	7	29 (NS) a	17 (NS) b	46 (NS) c
Bulk method	7	0	0	2	4	5	2	4	5	5	5	0	0	8	22	25	47

<sup>a</sup> P/L = 3.0, N = 10 (total measuring points, 1–14 = 140).<sup>\*</sup> vs. Bulk method (Mann–Whitney U-test, S: significant difference, NS: not significant difference, alpha = 0.05).<sup>#</sup> Values with the same letters were not significantly different by Tukey test ( $p > 0.05$ , non-parametric [19]).

### 3.1.2. Storage and polishing procedures

The surfaces of designated restorations were polished immediately after light curing, with abrasive points while rinsing with distilled water in an effort to avoid desiccation and breakdown. The other designated specimens were stored after light curing in distilled water at 37 °C for 24 h. Then the surfaces of the restorations were polished.

### 3.1.3. Inspection procedures

Each tooth was sectioned in a buccolingual direction through the center of the restoration with a low-speed diamond saw. The presence or absence of marginal gaps was measured at 14 points (each 0.5-mm apart) along the cavity restoration interface ( $n = 10$ ; total points measured = 140) using a traveling microscope. The number of gaps in each position was totaled and expressed as a sum for each sample, as described above.

### 3.2. Results

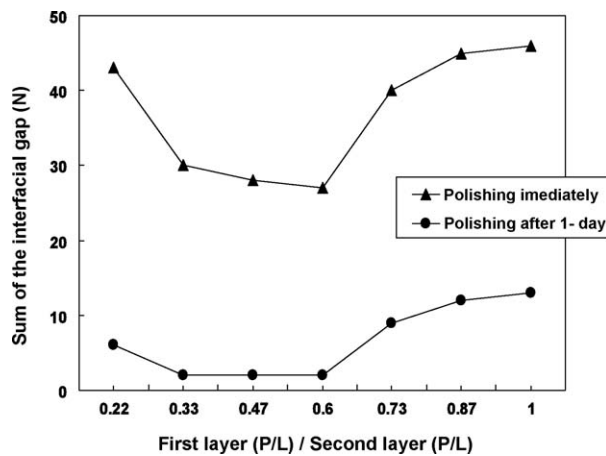
**Table 3** summarizes the interfacial gap-formation observed in the root surface restorations with *Fuji II LC* at various normalized powder/liquid ratios of the first increment, when the specimen was polished immediately after light-activation. In the coronal and cervical regions, the sums of gaps were not significantly different for the various P/Ls of the first increment, and also not significantly different compared to the bulk method. In the axial region, when the normalized P/Ls of first increment were 0.33, 0.47 and 0.6, the sums of gaps were 10–11 and were significantly smaller than for the bulk method. Considering totals for all regions, when the normalized P/Ls of the first increment were 0.33, 0.47 and 0.60, the observed sums were 27–30 gaps, which was significantly less than with the bulk method. However, the sums of gaps were not significantly

**Table 4** Effect of normalized powder/liquid ratio of first layer (incremental method) on interfacial gap-formation around *Fuji II LC* restorations, polished after 1-day storage.

Normalizd P/L ratios	Number of specimens showing gaps													Sum			
	Coronal				Axial						Cervical				Coronal + cervical	Axial	Total for all
	1	2	3	4	5	6	7	6	9	10	11	12	13	14			
Incremental method: first layer (P/L)/second layer (P/L) <sup>a</sup>																	
0.20	0	0	0	1	0	0	1	1	2	1	0	0	0	0	1 (NS) <sup>*</sup> A <sup>#</sup>	5 (NS) B	6 (NS) DE
0.33	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1(NS) A	1 (S) B	2 (S) E
0.47	1	0	0	0	0	0	0	0	0	0	1	0	0	0	2 (NS) A	0 (S) B	2 (S) E
0.60	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0 (NS) A	2 (S) B	2 (S) E
0.73	0	0	0	1	2	2	0	1	1	1	1	0	0	0	2 (NS) A	7 (NS) BC	9 (NS) DE
0.87	0	0	0	1	1	3	1	1	2	2	1	0	0	0	2 (NS) A	10 (NS) C	12 (NS) D
1.0	0	0	0	0	1	1	4	1	1	3	2	0	0	0	2 (NS) A	11 (NS) C	13 (NS) D
Bulk method	0	0	0	3	3	3	3	2	2	2	0	0	0	0	3	15	18

<sup>a</sup> P/L = 3.0, N = 10 (total measuring points, 1–14 = 140).<sup>\*</sup> vs. Bulk method (Mann–Whitney U-test, S: significant difference, NS: not significant difference, alpha = 0.05).<sup>#</sup> Values with the same letters were not significantly different by Tukey test ( $p > 0.05$ , non-parametric [19]).





**Figure 3** Variation of the total interfacial gap-incidence with the normalized P/L ratio of the first increment of Fuji II LC, for both immediate and delayed (24 h) specimen polishing conditions.

different for the remaining P/Ls of the first increment. The surface locations: 1 and 14 (Fig. 2), showed a high incidence of gaps, for this condition. The variation of sums-of-gaps with normalized P/L ratio for increment 1 is shown in Fig. 3.

Table 4 summarizes the corresponding data for gap-formation of Fuji II LC observed in the restorations after delayed polishing. In the coronal plus cervical regions, the sums of gaps were not significantly different among all P/Ls of increment 1, and also not significantly different from the bulk method. In the axial region, for normalized P/Ls of 0.33, 0.47 and 0.60, only 0–2 gaps were observed, which was significantly less than for the bulk method. No significant differences were observed between the sums-of-gaps for three other P/Ls. Considering totals for all regions, for normalized P/Ls of 0.33, 0.47 and 0.60, the sums-of-gaps were only 2, again significantly less than for the bulk method (Fig. 3). The

surface locations: 1 and 14, showed almost no gaps for this condition.

Table 5 compares the sums-of-gaps with Fuji II LC restorations with various P/Ls, for immediate *versus* delayed polishing. In the coronal plus cervical regions, gaps were significantly fewer with delayed polishing, compared to immediate polishing. For sums-over-all-regions, gaps were also significantly fewer with delayed polishing, compared to immediate polishing.

#### 4. Effect of delayed polishing of Class I gap-formation with highly viscous glass-ionomer restorations

##### 4.1. Procedure

A Class I cavity was prepared in the human premolar surface, having a length of 3.5 mm, a width of approximately 2 mm with a depth of 1.5 mm under wet conditions (Fig. 4). Cavo-surface walls were finished to a butt joint. This design differed from a Class I clinical cavity in that cavity corners were geometric-box angles to prepare a constant-volume model.

The surfaces of designated restorations were polished immediately after setting, with abrasive points, while rinsing with distilled water in an effort to avoid desiccation and breakdown. The other designated specimens were stored after setting in distilled water at 37 °C for 24 h. Then the surfaces of the restorations were polished [21].

##### 4.1.1. Inspection procedures

Each tooth was sectioned in a buccolingual direction through the center of the restoration with a low-speed diamond saw. The presence or absence of marginal gaps was measured at 14 points (each 0.5-mm apart) along the cavity restoration interface ( $n = 10$ ; total points measured = 140) using a traveling microscope. The number of gaps in each position was totaled and expressed as a sum for each sample, as described above.

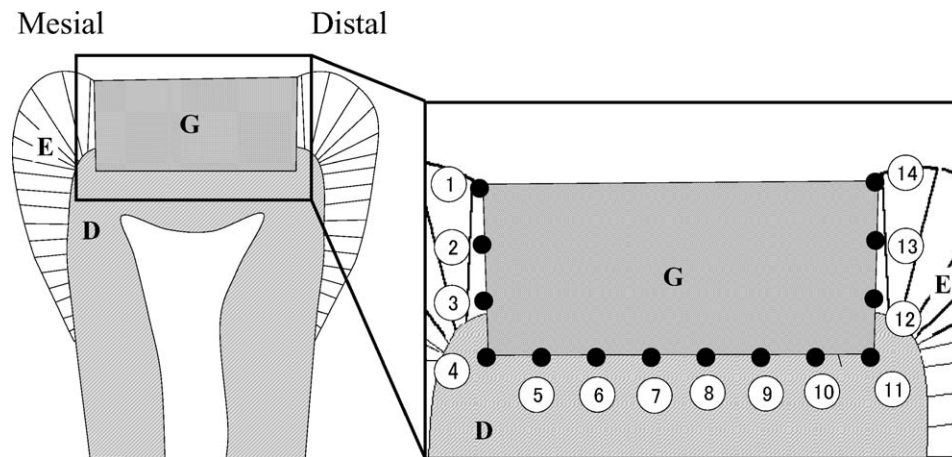
**Table 5** Effect of immediate *versus* delayed polishing technique on interfacial gap-formation around Fuji II LC restorations.

Sum of the interfacial gap for all 10 specimens

	Polishing immediately			Polishing after 1-day storage			Alpha value <sup>*</sup>		
	Coronal + cervical	Axial	All	Coronal + cervical	Axial	All	Coronal + cervical	Axial	All
Incremental method: first layer (P/L)/second layer (P/L) <sup>a</sup>									
0.20	20	23	43	1	5	6	S	S	S
0.33	19	11	30	1	1	2	S	S	S
0.47	18	10	28	2	0	2	S	S	S
0.60	17	10	27	0	2	2	S	S	S
0.73	21	19	40	2	7	9	S	S	S
0.87	22	23	45	2	10	12	S	NS	S
1.0	29	17	46	2	11	13	S	NS	S
Bulk method	22	25	47	3	15	18	S	NS	S

<sup>a</sup> P/L = 3.0,  $N = 10$  (measuring points, 1–14 = 140).

<sup>\*</sup> Significantly different by Mann–Whitney *U*-test between the two sums (S: significant difference, NS: not significant difference,  $\alpha = 0.05$ ).



**Figure 4** Class I restoration and each measurement locations for gap-formation. E: enamel substrate, D: dentin substrate, G: glass ionomer restorative material.

## 4.2. Results

Table 6 summarizes the interfacial gap-formation observed in the Class I with three highly viscous conventional glass-ionomer cements (HCGIC) and a normal conventional glass-ionomer cement (as a control), when the specimen was polished immediately after light-activation and after delayed polishing. For all materials, the sums of gaps were significantly fewer with delayed polishing, compared to immediate polishing.

## 5. Discussion

### 5.1. Delayed polishing

This study clearly demonstrated that the polishing of two filled glass ionomers (RMGIC and CGIC) should not be performed immediately after the filling and setting in the coronal cavity. For example, it demonstrated that polishing (Tables 1 and 2, #2) or not polishing procedure (Tables 1 and 2, #1) did not prevent gap-formation immediately after

**Table 6** Effect of polishing time on gap-formation around Class I restoration.

Manufacturer restoration	Polishing time	Number of specimens showing gaps														Sum		
		Medial				Bottom				Distal				1+14	2–13	Total for all		
		1	2	3	4	5	6	7	8	9	10	11	12				13	14
<i>Fuji IX GP</i>	Immediate	10	5	2	4	2	1	7	7	7	3	7	6	9	10	20 (NS) <sup>a</sup> S <sup>c</sup>	60 (NS) <sup>c</sup> S	80 (NS) <sup>g</sup> S
	After 1-day storage	2	0	0	0	0	1	1	0	0	0	0	0	0	5	7 (NS) <sup>b</sup>	2 (S) <sup>e</sup>	9 (S) <sup>i</sup>
<i>Glaslonomer FX-II</i>	Immediate	9	5	4	4	2	5	6	5	7	7	7	3	6	10	19 (NS) <sup>a</sup> S	61 (NS) <sup>c</sup> S	80 (NS) <sup>g</sup> S
	After 1-day storage	5	0	0	0	0	1	0	0	0	0	1	0	0	5	10 (NS) <sup>b</sup>	2 (S) <sup>e</sup>	12 (NS) <sup>i</sup>
<i>Ketac Molar Aplicap</i>	Immediate	10	6	6	5	6	5	7	9	5	7	8	9	6	10	20 (NS) <sup>a</sup> S	79 (NS) <sup>d</sup> S	99 (NS) <sup>h</sup> S
	After 1-day storage	4	0	0	2	0	1	0	2	2	1	4	2	0	3	7 (NS) <sup>b</sup>	14 (NS) <sup>f</sup>	21 (NS) <sup>j</sup>
<i>Fuji II</i> (as a control)	Immediate	10	5	4	4	5	7	10	10	6	3	7	6	7	10	20 S	74 S	94 S
	After 1-day storage	7	0	0	2	0	2	1	1	0	2	1	0	1	4	11 S	10 S	21 S

N = 10 (total measuring points, 1–14 = 140).

<sup>a</sup> vs. Fuji II (Mann–Whitney U-test, S: significant difference, NS: not significant difference, alpha = 0.05).

<sup>b</sup> Means with the same letters were not significantly different by Tukey test ( $p > 0.05$ , non-parametric [19]).

<sup>c</sup> Immediate versus After 1-day storage (Mann–Whitney U-test, S: significant difference, alpha = 0.05).

setting. Polishing/unpolishing should be delayed to a later time to prevent gap-formation at the material-tooth cavity interface. In contrast to the presence of approximately 100–120 of 140 (total measured points) gaps at the material–tooth cavity interface in the coronal cavity of specimens was polished immediately after setting, the gap was near zero when the specimen was polished after storage in water for 1-day. RMGIC or CGIC shrinks during the setting reaction. A gap was formed as the adhesion between the tooth cavity and glass ionomer did not resist the stress formed by cement shrinkage [22,23]. One reason for this dependence of the gap on the storage period may be the hygroscopic expansion of the glass ionomer due to an apparent correlation of the marginal gap in tooth cavity with the marginal gap in a Teflon mold was observed for the condition after 1-day storage [14]. This effect was reported for the uptake of water by the matrix of RMGICs forming a poly-HEMA complex [10]. In addition, GIC forms a hydrogel of calcium and aluminum polyacrylates by the uptake of water [9]. After 1-day water storage, the curing contraction stresses of the materials are effectively compensated for or even converted into expansion stress due to water uptake and swelling [24]. Water absorption of RMGICs and CGICs reportedly affects cavity adaptation and reduces microleakage [14]. Although hygroscopic expansion may not be enough to compensate for the setting shrinkage, it plays an important role in reducing the shrinkage caused by the cement setting reaction and thus improves the marginal seal [16,24,25]. There seems to be no regard for the fact that some materials can develop a significant radial pressure as a result of water absorption.

The cement is expected to that the cement shows higher bond and mechanical strengths when fully set rather than during setting reaction. It is suggested that the bond ability to the tooth substrate increases with the development of the glass ionomer/tooth substrate interaction during storage in water, and that the cohesive strength of the cement itself improves with the setting process [14]. The pH, an index of the degree of the hardening reaction of set glass ionomer, is reported to be lower at the initial stage regardless of the type of cement, that is, GICs or RMGICs. The pH value of the set cement gradually increases for 24 h [26,27]. Therefore it can be presumed that completing the setting reaction of a RMGIC or GIC requires 24 h. Thus, 24 h are required until a RMGIC or GIC has adequate mechanical strength, which has a close relationship with the bond strength [14]. RMGI has a dual setting reaction: one is light-initiated cross-linking of methacrylate groups similar to the setting of light-cured resin composites, the other is an acid–base reaction similar to that of a GIC [10,11].

## 5.2. Reduced P/L ratio of the first increment

The results show that using low P/Ls (similar to a luting type), as the first increment, significantly reduces gap-formation, especially with *Fuji II LC*, at both axial and all-interfacial regions, with immediate polishing. It was proposed that the incidence of gap-formation of a resin-composite in a cavity is determined by (1) the adhesion forces between the restorative material and cavity walls, (2) the size of the volumetric contraction of the restorative materials and (3) its viscosity or ability to flow [28]. In the initial stage during setting, when the restorative material still adheres to the cavity walls, the

shrinkage will be released as a flow of restorative material from the free surface. When the shrinkage-stress, in a vector direction from the tooth substrate wall to the center of the restorative materials, exceeds the strength of bonding, steadily increasing gap-formation will occur along the cavity walls, as long as the setting process continues. Comparing the restorative materials with different fluidity, through reduced P/L of the first increment, the flow from the free surface will increase by increasing fluidity of the restorative material and – other factors being equal – will give decreasing shrinkage-strain at the interfacial gap in the cavity base. However, a low P/L also tends to produce increased setting-shrinkage, which tends to aggravate gap-formation. In this study, enhanced setting-shrinkage may have had a negative effect on gap-formation and a limiting effect on the gap-reducing capacity of the lowest P/Ls of RMGIC. That could explain the upturn in gap-incidence at a normalized P/L of 0.2 seen in Fig. 3. However, because the manufacturers' recommended P/L mixture of RMGIC was used for the second increment, the net result of the counteracting effects was generally favorable, giving overall reductions in gap-incidence.

## 5.3. Highly-viscous glass–ionomer restoration

After 1-day storage a HCGIC (*Fuji IX GP*) performed significantly better than its corresponding conventional CGIC (*Fuji II*). Increasing powder–liquid ratio is the main reason for improving these results, as the two CGICs are otherwise very similar. This improvement is achieved by a reduction in the glass particle-size. However Glaslonomer FX-II and Ketac Molar Aplicap did not clearly show this pattern. This may be explained by differences in density, distribution or content of the powder, and the polyacrycid or maleic acid concentration or molecular weight of polyacrycid or maleic acid of the liquid. A number of variations led to a HCGIC with improved physical properties [29].

## 6. Significance

The interfacial gap-formation behavior can be interpreted in terms of the contributions of flowability, bonding, shrinkage and compliance of components, along with compositional features of the restorative materials. With restorative materials it is generally inadvisable to polish the interfacial marginal surface immediately after light-activation or setting. The polishing procedures should be carried out not less than 24 h later as a whole.

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